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TREATMENT NEEDED BY SEWAGE BEFORE INJECTION WELL RECHARGE

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New York State Department of Health
Albany, New York

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SUMMARY STATEMENT

Injection wells provide a safe, economical, and effective means of recharging substantial quantities of waste water to the ground water supply. However, the problem of major importance in connection with injection well recharge is the clogging of the soil pores at the soil and water injection interface and in the soil in the immediate vicinity of the injection well.

Two clogging factors, physical and biological, were observed after recharge of either fresh water or filtered secondary treated sewage effluent. Both factors were studied in the simulator sampling tube during injection. Physical clogging was found to be associated with the mixing of the filter pack material with the aquifer at the interface and the penetration of soil fines in the direction of water flow. Biological clogging was found to be associated with the presence of algal and organic material. Both clogging processes took place at the same time during injection.

Experimentation with combination beds of sand and anthracite, sand, anthracite and carbon, and single beds of sand or anthracite led to the choice of anthrafilt filter media as producing the longest filter runs and the best effluent quality.

PROJECT STAFF

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*All were employed during the entire project period.

Parenthesis () indicate the percentage of their time devoted to the project.

PUBLICATIONS SUPPORTED BY THE PROJECT GRANT

1. Stevens, D.B., Peters, J., "Long Island Recharge Studies." Jour. Water Poll. Cont. Fed., 38, 2009-2020 (1966).

2. Stevens, D.B., "Wastewater Reuse - Status in New York State." Presented at the 40th Annual Meeting of the Water Pollution Control Federation, New York City (Oct. 1967).

PART I - GENERAL

INTRODUCTION

This study resulted from the need to provide sewerage for Suffolk County, New York, and at the same time conserve its water resources. The applicability of the data to be derived from this research to situations in other parts of New York State, as well as nation-wide, is also recognized.

Waste water reclamation via artificial recharge to ground water is a water supply method offering economy, abundant underground storage, safety from radioactive fallout, and prevention of salt water intrusion.

The use of injection wells for artificial recharge provides a means of using a minimum amount of land for recharge purposes. The competition of various public uses for land is great. Injection wells can be located on land used for other purposes such as highways, recreational areas, and public buildings. Where water bearing aquifers are sealed off from the ground surface by clay layers or other aquicludes, injection wells provide the only means of recharge "in situ" of available recharge water. Contaminants from surface run-off cannot reach injection wells and no insect breeding is possible as compared with water spreading areas.

Sewerage and sewage treatment provide a means of controlling pollution of the ground water resource. The reclamation of waste water via artificial recharge to underground aquifers is a means of preventing the depletion of existing ground water resources by providing an avenue for waste water reuse. The soil mantle is a water purifying agency which by reason of water storage and water travel therein can bring about physical, chemical, and bacteriological changes in the water contained in its pores.

The rate of application of reclaimed water to the infiltrative interface surface of underground formations as considered in this study is several hundred times that associated with infiltration rates for septic tank and cesspool effluents and about one hundred times the rate of application for recharge basins used for waste water reclamation.

The artificial recharge of renovated waste water is a means of preventing salt water intrusion into underground aquifers by maintaining ground water reservoirs above critical levels.

The problem of major importance in connection with artificial recharge via injection wells is the clogging of the soil pores at the soil and water injection interface and in the soil in the immediate vicinity of the injection well.

Thus these studies have been dedicated to injection well clogging by the use of a pilot plant model on a demonstration basis. Data was also obtained on other facets of waste water reclamation via artificial recharge.

OBJECTIVES

This research is intended to provide data and operating experience in the following broad categories:

1) The effect of high rate filtration through sand and anthracite, on secondary waste water treatment plant effluent in relation to injection well clogging from the following standpoint:

a. Economics of different filter media for production of effluent suitable for well injection.

b. Relationship of secondary treatment plant effluent to injection well performance.

c. Relationship of filtered water to injection well performance.

2) The design and operation of injection wells for reclaimed waste water in relation to:

a. Reasons for clogging.

b. Methods for redevelopment after clogging and effectiveness thereof.

3) Manner of dispersion and hydraulic aspects of dispersion of injected water.

4) The effect of underground travel on the quality of injected water.

PILOT PLANT

The pilot plant constructed at Riverhead, New York, represents a model for the transportation of secondary sewage treatment effluent into the ground via injection wells, after tertiary treatment by a rapid sand filter.

The pilot plant as constructed incorporated the following units:

a) A lift pump to pump secondary clarrifier effluent from the high rate trickling filter to the pilot plant. The pump is capable of providing up to 140 gallons per minute to the filter.

b) A hypochlorinator to feed chlorine solution to the pump discharge.

c) The pilot plant filter comprised of eight cells, each five square feet in area providing a total filter area of forty square feet. The filter was wired for automatic backwashing upon cell reaching maximum allowable head loss. One cell backwashes at a time.

d) A filtered water storage tank to provide water for filters washing and to provide a suction well for pumping filter effluent to the ground well and simulator well.

e) A ground well.

f) A ground simulator and well. This device enables sampling of the filter pack-aquifer interface and the aquifer material within four feet of the simulator well.

The model was designed to permit evaluation of:

1) The unit operation of liquid transport through the rapid sand filter.
2) The unit operation of liquid transport by infiltrative passage through the aquifer interface of the injection well.
3) The unit operation of liquid transport through a porous media aquifer.
4) The unit processes involved in the clogging of the infiltrative interface and the pores used for percolative travel during transport through a porous media aquifer.
5) The unit processes involved in changes of quality in applied recharge water by reason of percolative travel through a porous media aquifer.

The model was designed to permit sampling, for study, of the injection well, filter pack material adjacent to the well screen, and the filter pack* and aquifer material at the aquifer interface.

The model was also designed to enable sampling for study of the aquifer material at the level of the well screen within a horizontal four foot radius from the center of the injection well.

Components of the model are a rapid sand filter and a simulated injection well in a tank above ground with removable aquifer sampling tubes. An actual ground injection well for parallel operation was also constructed with satellite observation wells permitting ground water level measurements and ground water sampling.

The model was designed to prevent air entrainment in the liquid transported. However, for this phase of the work, dissolved or chemically bound gases that are normally present were not removed.

*Note: In this report, the words "filter pack" and "gravel pack" are used synonomously.

SUMMARY

PHYSICAL CLOGGING FACTORS - Two major physical clogging factors were observed after recharge of either fresh water or filtered sewage effluent:

1. The aquifer materials invaded the filter pack producing one with more fines.

2. There was a greater percentage of fines concentrated in the aquifer material within a four foot radius from the center of the injection well.

Both of these effects may be observed on Plate A on the gradation curve designated "Gravel Pack After Recharge." Those observations were made by the sieve analysis of the material in the simulator sampling tubes after fresh water and filtered sewage effluent recharge.

During the application of the recharge liquid, there was a progressive increase in piezometoic level in the filter pack and inside the well casing. The water level configuration during recharge is shown on Plate E. While the difference between water levels in casing and in the gravel pack may reflect hydraulic energy release and screen opening efficiency, the difference in water level between gravel pack and aquifer shows the clogging problem at the infiltrative interface.

The pilot plant ground well and simulator well filter pack met both the Corps of Engineers and the E.E. Johnson Co. size criteria for filter pack in relation to aquifer particle size gradation. The screen size criteria of the Corps of Engineers were met but not the E.E. Johnson Co. screen size criteria which requires that the screen opening retain 90% of the filter pack. However, at no time, either during pumping or recharge, did any of the filter pack material enter the well.

The sieve analysis, after fresh water injection, of the material in the simulator sampling tubes was made after the aquifer material had been subject to recharge only. In case of filtered sewage effluent injection, some of the sieve analyses were made after both injection and redevelopment pumping.

As may be seen from Plates L, LI, LII, and LIII, the mixture of aquifer and filter pack material becomes more pronounced after both recharge and redevelopment pumping as compared with recharge alone. Note the greater proportions of fines in the filter pack material as compared with pure filter pack material. These observations, plus the loss of specific capacity after recharge as shown on Plate D, and taking into account the slow rate of clogging when fresh water is used for injection, have led to the conclusions that the mixing of aquifer and filter pack material upon recharge is a contributory cause of interface clogging. The proportionate contribution of this mixing is taken to be greatest with fresh water which lacks particulate matter and a large measure of organic material. The more pronounced mixing of filter pack and aquifer upon alternate pumping and recharge represents a long term clogging effect in relation to injection well performance.

The approximate application rates in the ground well and simulator well during recharge of both fresh water and filtered sewage effluent were 140 feet per day for the interface measured opposite the well screen and 70 feet per day measured from the static level of ground water to the bottom of the recharge well. These are to be compared with 1 foot per day, a common case for recharge basins.

The pattern of flow through the interface may be seen on Plate H to follow that previously reported by McGauhey and Winneberger, i.e. - a period of decreasing permeability while the soil is being slaked, followed by a period of increasing permeability during which entrapped air is removed, and a final phase of long term permeability decrease resulting from microbial activity. In test No. 2 in Plate H the slaking step is absent since the tests followed each other.

BIOLOGICAL CLOGGING FACTORS - Biological clogging associated with organic matter was studied by the application of filtered sewage effluent

to the simulator well and the ground well, observing water levels, analyzing the filter pack and aquifer material in the simulator sampling tubes, and subjecting it to microscopic analysis.

Fresh Water Injection - The water used for the fresh water test was potable water from the Riverhead public supply mains. This is a clear water, devoid of suspended solids with chemical analysis as shown on Table I.

After fresh water injection, the simulator sampling tube was removed and the aquifer contents were tested for organic material. The natural organic content in the soil was measured at 0.17%. The measured concentration of organic material occurred after 22 days of fresh water injection.

As may be seen from Plate I, although diminishing in concentration, the organic material in the applied water travelled the full four feet of the sampling tube, and at that distance was 0.30% by weight of the aquifer material.

Microscopic examination of the filter pack-aquifer interface revealed the presence of blue green algae identified as Anabaena and the crenothrix form of sphaerotilus. As may be seen from Curve 6, Plate G, the numbers of organisms were very small. The crenothrix has been known to exist in the Riverhead water supply.

The rate of clogging of the ground well with fresh water injection was slow and although piezometric surface rose steadily in the filter pack material, the well was only half clogged to the point of requiring re-development after four months of fresh water injection.

Filtered Sewage Effluent Injection - Filtered sewage effluent injection was characterized by variable quality of liquid to be transported. Plate B shows hourly variations in concentrations of phosphates, nitrogen compounds, solids, carbon dioxide, pH, and alkalinity. Daily and seasonal variations were also of considerable magnitude.

The biological clogging effects were studied by chemical analysis and microscopic examination of the simulator sampling tubes after periods of injection and redevelopment by pumping with fresh water. Various runs were made by adapting the simulator well for saturated conditions and as a diffusion well above the ground water table.

A typical analysis of the aquifer material in the sampling tube is shown on Plate F. This particular analysis was made after seven days of filtered sewage injection. Organics, nitrates, nitrites, ammonia, & phosphates are greatest at the interface but remain substantially high within the total four foot length of the sampling tube.

The algal numbers at the filter pack-aquifer interface for various test runs are shown on Plate G. Numbers were greatest at the interface for the most part. However, in some samples, chemical constituents and algae were higher at the casing-filter pack interface. Bacterial numbers measured as MPN coliforms were great in the interface material as compared with their numbers in the applied liquid and remained great after redevelopment.

The predominating algae identified were Scenedesmus and Ankistrodesmus. Predators in the form of protozoa, rotifers, and nematodes were also present at the interface when filtered sewage effluent was injected.

When operating under unsaturated conditions as an injection well above the ground water table, more algae were found at the interface. Redevelopment with fresh water increased the algae present.

Under saturated conditions, redevelopment with fresh water decreased the phosphate, ammonia, nitrite, and nitrate present at the interface. For unsaturated conditions, redevelopment did not materially washout any of the constituents at the interface.

The differences in algal organisms at the interface for fresh water injection compared with filtered sewage effluent injection is shown in Plate G.

Both physical and biological clogging were studied in the simulator sampling tube during the injection of fresh water. Physical clogging was found to be associated with the mixing of the filter pack material with the aquifer at the interface and the penetration of soil fines in the direction of water flow. Biological clogging was found to be associated with the presence of algal and organic material. Both clogging processes took place at the same time during injection.

Phosphates predominate in quantity at the interface and nitrates take second place in quantity. A rapid reduction in the biological nutrients was found within three feet of the aquifer-filter pack interface. However, the indication is that they can carry far, particularly phosphates which exhibit the flattest characteristics.

Any increase in nutrients which occurred at the four foot distance in the sampling tubes are believed due to the manner of packing the tube.

The observation well quality determinations revealed a large increase in ammonia content after 15 feet of travel from the injection well with a concomitant reduction in nitrate and nitrite. The formation of an zone for reduction of oxidized nitrogen is indicated.

Another factor of significance observed from observation well water level readings was the fact that the head loss between observation wells during filtered sewage injection was 2 to 3 times that observed for fresh water injection.

The algae observed at the filter pack-aquifer interface, i.e. - Scenedesmus, are capable of chemosynthetic metabolism in the dark. The non-photosynthetic incorporation of carbon dioxide is known to occur at a slow but steady rate.

Carbon dioxide has been found to be an essential metabolite for growth (Hunter and Provasoli, 1951; Woods and Vascelles, 1954; Davies, 1959). Carbon dioxide has always been present in the trickling filter and rapid sand filter effluents in the Riverhead tests. McKinney (1962) states that metabolism in the dark requires oxygen and that the demand for oxygen by algae in the absence of sunlight is of as much importance as the production of oxygen by algae. The liquid applied to the interface has always contained oxygen for the Riverhead tests.

Many experiments have been made by various investigators with Scenedesmus because it can easily be cultured. When cells of Scenedesmus are incubated in the dark, there is a slow steady uptake of the labeled carbon dioxide amounting usually to less than 1% of the maximum pick-up available in the light and not detectable by the usual manometric techniques.

The uptake of phosphate by Scenedesmus is considerably greater in the light that in the dark. The phosphorous content of Scenedesmus (Gaffrons Strain D_3) cells were shown to depend strictly on the concentration of phosphates in the medium. Goodman et al (1955) found that the polyphosphates in Scenedesmus algae represent 21% of the total phosphate content.

Both Ankistrodesmus and Scenedesmus have been found by various investigators to exhibit hydrogenase activity. This involves the use of molecular hydrogen for nitrate and nitrite reduction to the level of ammonia in the absence of oxygen.

Various investigators have found that trace elements are involved in nitrogen metabolism by algae. In Scenedesmus and Anabaena, molybdenum is required for growth on nitrate but not for growth on ammonium N or urea. Wolfe (1954) concluded that the absence of molybdenum not only affects the reduction of nitrate by Anabaena cylindria but also the synthesis of proteins. Manganese seems necessary for complete reduction of nitrate by Ankistrodesmus.

The protozoans found at the filter pack-aquifer interface after recharge of filtered sewage effluent also indicated an aerobic environment.

RAPID FILTRATION

Experimentation with combination filter beds of sand and anthracite, sand, anthracite and carbon, and single beds of sand or anthracite led to the choice of anthrafilt filter media as providing the longest filter runs (about 24 hours) and the best effluent quality.

As illustrated on Plate C, the filter removes nitrite, BOD, suspended solids, and bacteria. The filter efficiency is a direct function of the concentrations in the applied liquid. Filter effluent deteriorates when the influent liquid to the filter contains a greater concentration. A considerable drop in carbon dioxide content was noted across the filter and dissolved oxygen content increased by aeration in passage through the filter.

The biological nutrient materials including phosphates, nitrates, and surfactant materials were removed in very small degree or showed increases by reason of filtration.

CHLORINATION

It was found that the addition of no chlorine at all gave very short filter runs (about 3 to 4 hours). The addition of 1.5 ppm chlorine increased filter runs to 24 hours. However, the addition of substantial amounts of chlorine to the breakpoint and to development of a free residual, increased turbidity and formed excess amounts of chlorides and increased the oxidative potential, thus interfering with tests for oxidized nitrogen and surfactant materials. Also, the oxidation of organic matter by chlorine addition did not provide a true measure of filter performance.

UNDERGROUND TRAVEL EFFECT ON WATER QUALITY

The effect of underground travel on water quality was studied in two ways. One was the effect of travel through four feet of simulator contents and the other was the effect as measured by observation well sampling.

Further filtration through the aquifer pores, as may be seen in Plate C, removed ammonia, nitrite, BOD, COD, turbidity, suspended solids, alkalinity, and bacteria. The apparent increases in nitrates, nitrites, phosphates, and surfactant materials are believed due to the inadequacy of the Standard Methods Test where chloride, organic matter and oxidative potential, and adsorptive interferences are present. The increase in carbon dioxide through the simulator is unexplained.

Underground travel effects as observed in the ground observation wells showed that after fresh water injection, the area covered by the well field reached the quality of the injected water after 30 days of injection. The injected water was of better quality than the ground water.

After one month of filtered sewage effluent injection, at the rate of 20 gallons per minute (864,000 gallons injected), the most remote well (S-3) at a distance of 40 feet from the injection well showed the following: (The measured quality reflects the effects of dilution and quality changes due to underground travel.)

Chloride	44	ppm	Nitrate as N	.100	ppm
MBAS	0.72	ppm	Turbidity	36	ppm
Free Ammonia as N	24	ppm	Total Solids	318	ppm
			Coliforms	1.5	per ml
Nitrate as N	.009	ppm			

There was evidence that reduction of nitrate to ammonia took place in underground travel at some point between 5 and 15 feet from the injection well.

SURFACE TENSION MEASUREMENTS

Surface tension measurements indicated that the domestic water supply

and the ground water had higher surface tension than the sewage effluent. Depressed surface tension of the sewage effluent is believed due to the presence of surfactant materials and ammonia. The depressent effect of these materials was greater than the increase to be expected from dissolved salts.

At the filter pack-aquifer interface, the chemical analyses indicated that the tendency to lose nitrates and phosphates tended to further decrease the surface tension.

The injection of sewage into the ground well lowered the surface tension in the water sampled from the wells nearest to the ground well. The surface tension in wells furthest from the injection well was higher than in those nearest to the injection well.

VISUAL INSPECTION OF THE INTERFACE

Visual inspection of the clogged interface after filtered sewage effluent injection was made. No discoloration or slime was present. There was no detectable odor. Rolling it in the fingers indicated no evidence of slimy material or special organic matter. The migration of aquifer material into the filter pack was evident.

CONCLUSIONS

1. Long term physical clogging effects of injection wells involve the invasion of filter pack material by aquifer fines. This is due to application of recharge liquid alone.

2. The clogging effect described in (1.) is aggravated by alternate pumping and recharge.

3. Physical clogging is aggravated by and is coincident with pore clogging when organic material is present in the liquid being transported through the infiltrative interface.

4. The biological environment of the filter pack-aquifer interface is suited to autotrophic utilization of ammonia, oxidized nitrogen, phosphates, and carbon dioxide by species of algae which are able to carry on chemo-synthetic metabolism in the dark in the presence of oxygen. The hydrogenase activity of these algae may possibly be associated with reduction of oxidized nitrogen upon further penetration into the aquifer in travel away from the injection well.

5. The biological environment changes at some point between 5 and 15 feet from the injection well, so that oxidized nitrogen is reduced.

6. The head loss due to percolation through the aquifer of a filtered sewage effluent is 2 to 3 times that for fresh water. This is most probably associated with the presence of organic material and biological activity.

7. Rapid filtration of secondary effluents using anthracite filter media is practicable for removing suspended solids. Total organic matter and biological nutrients are little affected.

RECOMMENDATION

Additional experimentation should be performed with type of filtration which will remove greater amounts of organic matter and means of removal of dissolved gases, together with redesign of the filter pack for injection wells. Experimentation with means for nutrient removal is also desirable. The experimentation with dissolved gas removal is intended to be studied in its relationship to biological environment and not gas binding. Lengthening of one simulator tube to 15 feet is also desirable.

PART II - PILOT PLANT OPERATION

FILTER INFLUENT -

The plant piping was arranged so that the rate of flow to the pilot plant filter, to the ground injection well, and to the simulator well could be continuously and automatically controlled and recorded. At no time were turbulent flows applied. Reynolds numbers were always in the lower laminar range in the filter pack and aquifer.

The trickling filter effluent was characterized by extreme variability in quality with 5 day BOD ranging from 24 ppm to as high as 196 ppm. Hourly variations in phosphates, nitrogen, suspended solids, total solids, carbon dioxide, alkalinity, and pH can be seen on Plate B. While some of the variations are nominal for domestic sewage treatment, this particular case was complicated by the occasional discharge of industrial waste water from a duck evisceration plant into the Riverhead sewer system.

FILTER PERFORMANCE -

As a tertiary treatment device using anthracite media and influent chlorinated with 1.5 ppm of chlorine, the filter can be expected to remove about 40% of applied 5 day BOD and 60% of applied suspended solids.

The removal of ammonia is usually less than 10% of that applied. Nitrite removal was about 15%. Nitrates tended to increase in passage through the filter. The removal of nitrogen compounds and increase of nitrates is primarily due to the aerobic nature of the unit operation of transport of the liquid through the aquifer. The measured results are also due in some part to interferences with the test for nitrates. No removal of dissolved materials such as chlorides and sulphates can be expected. Such total solids that are removed are related to the suspended solids removal.

Bacterial removal efficiency is high but it reflects primarily the addition of chlorine. This is true of both coliform index and total plate count.

Operating experience indicated that a consistently good secondary effluent would be of advantage and that air wash, surface wash, and high velocity upflow wash would all be of advantage due to the relatively high temperature of the sewage effluent, particularly in the summer time. The actual facility used was a wash rate of about 10 gallons per minute per square foot, including a surface spray.

The operating experience also indicated that at least 90% of the filtered water was recoverable for use and that rapid sand filtration employing anthracite media is suitable and practicable for the filtration of secondary effluent. This is based upon two filter washes per day. Under optimum conditions of one wash per day, about 95% of the filtered water would be recoverable.

FRESH WATER INJECTION -

Fresh water injection in the ground well was continued for four months. The clogging rate as measured by the water level in the filter pack material was at the rate of 0.22 inches per day averaged over the four month period. The recharge rate was 20 gallons per minute which applied to the area of the aquifer interface amounts to 70 feet per day or 70 times the comparable rate associated with spreading basins. The area of application is taken to be the outside diameter of the filter pack material from the bottom of the injection well to the level of the ground water table. The height of water in the filter pack material indicates the clogging tendency of the area of the interface through which infiltration occurs. The transmissibility of the aquifer surrounding the well is about 140 times the applied rate of recharge flow measured at the interface area as derived

from the field coefficient of permeability. In Plate D are shown the drawdowns from pump tests before and after fresh water recharge. Specific capacity before recharge was 24.7 gallons per foot of drawdown in the well. The specific capacity after recharge was 12.3 gallons per minute per foot of drawdown.

Before injection of fresh water, a pump test was run with frequent readings of water levels in the well casing and in the observation wells. Permeability was calculated by the Thiem Formula and various other formulas. Different values were obtained depending upon the assumption made for use of the various equilibrium and non-equilibrium formulas. For purposes of comparison and discussion, the Thiem Formula results will be used. After the fresh water injection period of four months, the well was again pumped and the permeabilities were again calculated. No significant change in permeability in the percolative paths of travel of the applied recharge water were noticed. Thus the change in specific capacity is related to the infiltrative action of the liquid applied to the interface and not to the percolative action in flowing away from the immediate vicinity of the injection well, in so far as fresh water injection is concerned.

It was the purpose of the experiment to clog the injection well. This was accomplished after 33 days of filtered sewage effluent injection. At the time of clogging, gas bubbles were observed in the tremie wells in the filter pack material. The clogging was such that it was impossible to pump the well to any appreciable degree. The loss of specific capacity is shown on Plate D. The level observations, Table 2, show that the clogging was mostly in the aquifer and filter pack interface and somewhat in the zone within a five foot radius of the well. The sampling of the pumped water showed a sharp increase in pH, Table 3, indicating utilization of carbon dioxide by micro-organisms capable of photosynthetic type reactions in the dark. This

was borne out by the identification of the organisms in the simulator sampling tubes.

The rising trend of the water levels in the injection well casing and the tremie wells is apparent and represents the progressive clogging of the interface. The intermediate out of trend recessions in the water levels were found to be sensitive to small changes in the rate of flow applied to the well. The correlation of flow reduction with drop of the observed water levels is good.

Ground water quality and level in the observation wells was observed and recorded from time to time for about five months before injection of fresh water began. Quality and levels were observed once per week during the fresh water injection period.

Fresh water injection took place during a period of seasonal decline in the ground water table and the amount of injected water was insufficient to have any significant effect on the local water table. It was noticed that the ground water sampled from the observation wells reached the same quality as the injected water after 28 days of fresh water injection.

The pattern of water levels during injection into the simulator well was the same as that shown for the ground well on Plate E.

The particle size involved for the various media through which the sewage treament effluent was transported are shown in Plate A. The filter pack material for the injection well was the coarsest and most uniform. The anthracite rapid sand filter media was next in size and uniformity. The aquifer materials represent the smallest particle sizes and least uniformity. The relative gradations are typical of most practical applications. The quasi-parallel nature of the gradation curves shown in Plate A for filter pack and aquifer materials, represent a more advantageous infiltrative situation compared with gradation of a diverse nature.

The filter pack material gradation in relation to the aquifer material

size distribution and screen opening size met the criteria established by the Corps of Engineers for pressure relief wells and by the E.E. Johnson Co. for pumping wells. However, the screen opening did not meet the size requirement of the E.E. Johnson Co. for retaining 90% of the gravel pack material. The screen did retain 36% of the gravel pack material. No significant relationship to interface clogging could be ascribed to the screen opening need.

The criteria of the Corps of Engineers and the E.E. Johnson Co. are as follows:

CORPS OF ENGINEERS - for filtering stability

$$\frac{\text{15 \% finer size of filter pack}}{\text{15 \% finer size of coarsest aquifer materials}} < 20$$

$$\frac{\text{50 \% finer size of filter pack}}{\text{50 \% finer size of aquifer materials}} < 25$$

E.E. JOHNSON CO. -

$$\frac{\text{30 \% finer size of filter pack}}{\text{30 \% finer size of aquifer}} \geq 4$$

$$\frac{\text{30 \% finer size of filter pack}}{\text{30 \% finer size of aquifer}} < 6$$

Where symbol D_{10} equals particle size corresponding to 10% finer,

Screen opening $\leq D_{50\text{-}70}$ aquifer

" " $\leq D_{10}$ filter pack

The simulator was developed by pumping prior to fresh water injection, but the simulator sampling tubes were not developed by reverse flow prior to fresh water injection.

FILTERED SEWAGE EFFLUENT INJECTION -

Filtered sewage injection into the ground well was continued for 33 days before the well was considered to be clogged. The range of quality of the applied liquid was as follows:

BOD	22 to 60 ppm	pH	7.2 to 8.0
Suspended solids	4 to 30 ppm	MBAS	0.56 to 3.90 ppm
Phosphate (PO_4)	44 to 52 ppm	Total Plate Count	0 to 22×10^3
Nitrate as N	1.3 to 2.40 ppm	Chlorides	44 to 64
Free ammonia as N	13.6 to 19.2 ppm	Alkalinity	186 to 206

The clogging rate in the filter pack material was approximently 5½ inches per day at an application rate of 75 feet per day as applied to the area of the aquifer interface.

It may be seen from Plate D that the clogging tendency penetrated deeper into the aquifer, reaching beyond wells N-1 and S-1 as compared with fresh water injection. Thus the interface for infiltration into the aquifer becomes a problem in depth as compared with fresh water injection. Another difference is that when the initial high head-loss area between the injection well and about 5 feet therefrom is penetrated, the percolative head loss for deeper transport into the aquifer was about 2 to 3 times that for fresh water injection for approximently the same temperature. However, it may be seen from Plate D that once the interface area is infiltrated, the percolative permeability is much greater.

The primary differences between the two liquids are less surface tension, more dissolved and suspended solids, more organic matter, and more dissolved carbon dioxide in the sewage effluent. There are also more nutrients, such as phosphate and nitrogen, together with more biological life in the sewage effluent.

The pattern of water levels during sewage effluent injection was the same as shown on Plate E. When the water levels in the well casing and in the filter pack were about the same, the well was considered to be clogged.

Also to be taken into consideration is the fact that some loss of inter-

face infiltration capacity had occurred due to the recharge of fresh water and subsequent redevelopment pumping. The difference between water level inside the casing in the filter pack material was less than that for fresh water injection. Ground water quality and level in the observation wells were observed and recorded once per week during the sewage effluent injection period.

Dilution by reason of ground water mixing is calculated as follws, based upon chloride measurements:

Day after recharge began	PERCENT DILUTION Well S-1	Well S-2	Well S-3
6	56.0	64.6	78.8
21	52.4	63.0	56.0

In general, dilution increases as the injected liquid flows away from the injection well. Dilution calculations are influenced considerably by variability of data. The velocity of travel must be determined for accurate dilution calculations. Observation well quality seems to provide data suitable for only very general conclusions. Dilution was calculated by the following formula using chloride concentrations:

$$D = \frac{100(Cl_o - Cl_i)}{(Cl_r - Cl_i)}$$

where: D equals % dilution

Cl_o equals well equilibrium chlorides in ppm (observation well)

Cl_i equals chlorides in water injected in ppm

Cl_r equals chlorides in the recharged water (in the ground) prior to injection in ppm

The formula and the observations indicate that the percent dilution in the vicinity of the injection well decreases as injection progresses because the recharge mound tends to reach the quality of the recharged water. Dilution is available only by horizontal and vertical travel of the injected water

reaching the existing ground water. The recharge mound reached the quality of the injected water in about 30 days of injection within the limits of the available well field.

Bacterial travel was measured. Very few bacteria reached the outer observation wells but were still present at a distance of forty feet from the injection well.

The observation well quality data compared with the quality of the injected water indicates that when dilution is discounted, there is a considerable removal by underground travel of MBAS, phosphates, nitrate, and nitrite in excess of that accounted for by the dilution factor.

The observations of December 12 and 20, 1966, indicated that reduction of nitrogen was taking place as follows:

PPM AMMONIA NITROGEN AS N

	Well S-1	Well S-2	Well S-3
12/12/66	4.3	26.0	22.5
12/20/66	7.2	35.0	24.0

There were similar indications during injection of fresh water. The reduction process appears to be most marked at a distance of 5 to 10 feet from the injection well.

It was possible during the course of the work to clog the simulator well several times and observe and analyze the contents of the simulator sampling tubes and also to examine them microscopically.

The water levels during injection followed the pattern shown on Plate E. The simulator well was operated both as a diffusion well screened above the water table and as an injection well screened below the water table.

Analysis of the aquifer material in the sampling tubes after recharge and redevelopment was typically indicated in Plate F, with phosphates predominating.

The concentrations of the material adhering to the aquifer materials is greatest at the filter pack-aquifer interface. It is estimated that of the materials contained in the applied liquid, the following percentages were removed in travel through the four feet of the sampling tube.

Phosphate	0.0295 % removed
Ammonia (NH_3)	0.034 % removed
Nitrate	0.043 % removed
Nitrite	0.054 % removed
Organics	0.004 % removed

The 0.004% for the organics is based upon the applied organic material as measured by the volatile suspended solids test. However, the percent organics in the aquifer material was less after injection than it was in the natural sand, determined before injection. The reason remains obscure.

The above percents of removal were estimated after 6 days of injection. Thus, the percentage of these constituents leaving the applied liquid and remaining in the aquifer within the four feet of the well is very small.

Injection of filtered sewage effluent for one day instead of 6 days had a material effect on all constituents in a lesser amount retained in the aquifer material but was not proportional to time.

The order of magnitude of the materials determined in the aquifer materials after 6 days injection is as follows by weight:

Phosphates	0.0028%
Ammonia as NH_3	0.0016%
Nitrate	0.00061%
Nitrite	0.000087%
Organics	0.0001784%

While the above figures for removal and concentrations are averaged estimations, the significant factor is believed to be the small order of magnitudes involved.

Redevelopment by reverse flow of fresh water for 24 hours under saturated conditions washed out all constituents in some degree (generally 70% removed or more). All constituents remained in highest concentration at the interface of the aquifer even after redevelopment by reverse flow of fresh water

QUALITY COMPARISON
Municipal Water Supply and Trickling Filter
and Tertiary Treatment Effluent

	parts per million				
characteristic	Riverhead Water Supply	Range of Trickling Filter Effluent	Rapid Filtration Effluent (averages)		
			No chlorine Added	Chlorination to Breakpoint	Chlorination to free residual
total dissolved solids	64.0	205 to 642	315.0	300.0	317.0
chlorides	14.0	42 to 78	49.0	54.0	61.0
ammonia (free)	0.001	4.8 to 29.6	15.7	14.0	9.5
phosphate (PO_4)	1.14	6 to 125	39.0	36.0	30.9
MBAS	0.25	0.50 to 7.75	2.27	3.30	2.28
nitrates	0.04	0.07 to 4.25	0.48	0.84	1.24
iron	0.01	-	-	-	-
pH	7.85	6.80 to 7.90	7.35	7.60	7.79
CO_2	2.0	4.0 to 40.0	11.0	10.0	6.7
specific conductivity	100.0	325 to 625	489.0	474.0	445.0
total plate count	30	30 to 22×10^{10}	$.93 \times 10^{6}$	44	41

TABLE 1

SUBSIDENCE WATER LEVELS AFTER INJECTION WELL CLOGGING

Location	Elevation in Feet			
	At Clogging	One Hour After Clogging	Two Hours After Clogging	* Five Hours After Clogging
Injection Well	26.67	14.74	8.36	4.73
N.E. Gravel Pack	26.54	14.59=	8.91	Dry
S.W. Gravel Pack	24.58	15.21	8.98	Dry
E-1	8.36	7.94	7.64	7.47
E-2	7.81	7.71	7.61	7.53
N-1	8.19	7.91	7.62	7.49
N-2	7.75	7.67	7.57	7.49
W-1	8.24	7.90	7.63	7.46
W-2	7.74	7.66	7.55	7.49
S-1	8.18	7.83	7.61	7.46
S-2	7.71	7.61	7.56	7.46
S-3	7.54	7.54	7.56	7.44

* No significant change 24 hours after readings in this column.

TABLE 2

GROUND INJECTION WELL REDEVELOPMENT

AFTER

FILTERED SEWAGE EFFLUENT INJECTION

Turbidity and pH

Time	Turbidity 12/7/66	Turbidity 12/8/66	pH 12/8/66
11:00 A.M.	-	13-20	7.5
11:20 A.M.	-	3.5-11	7.8
11:30 A.M.	-	15.5-22	7.85
12:00 M	6.5-14	14-21	7.65
1:30 P.M.	-	27.5-32	9.35
2:00 P.M.	7.5-15	3.5-11	9.20
2:30 P.M.	-	27.5-32	9.10
3:00 P.M.	13-20	32.5-36	8.35
3:30 P.M.	10.5-18	25-30	7.15
4:00 P.M.	12-19	-	-

A sample taken from the injection well on 12/8/66 during pumping was analyzed as shown in Table XI - 3

TABLE 3

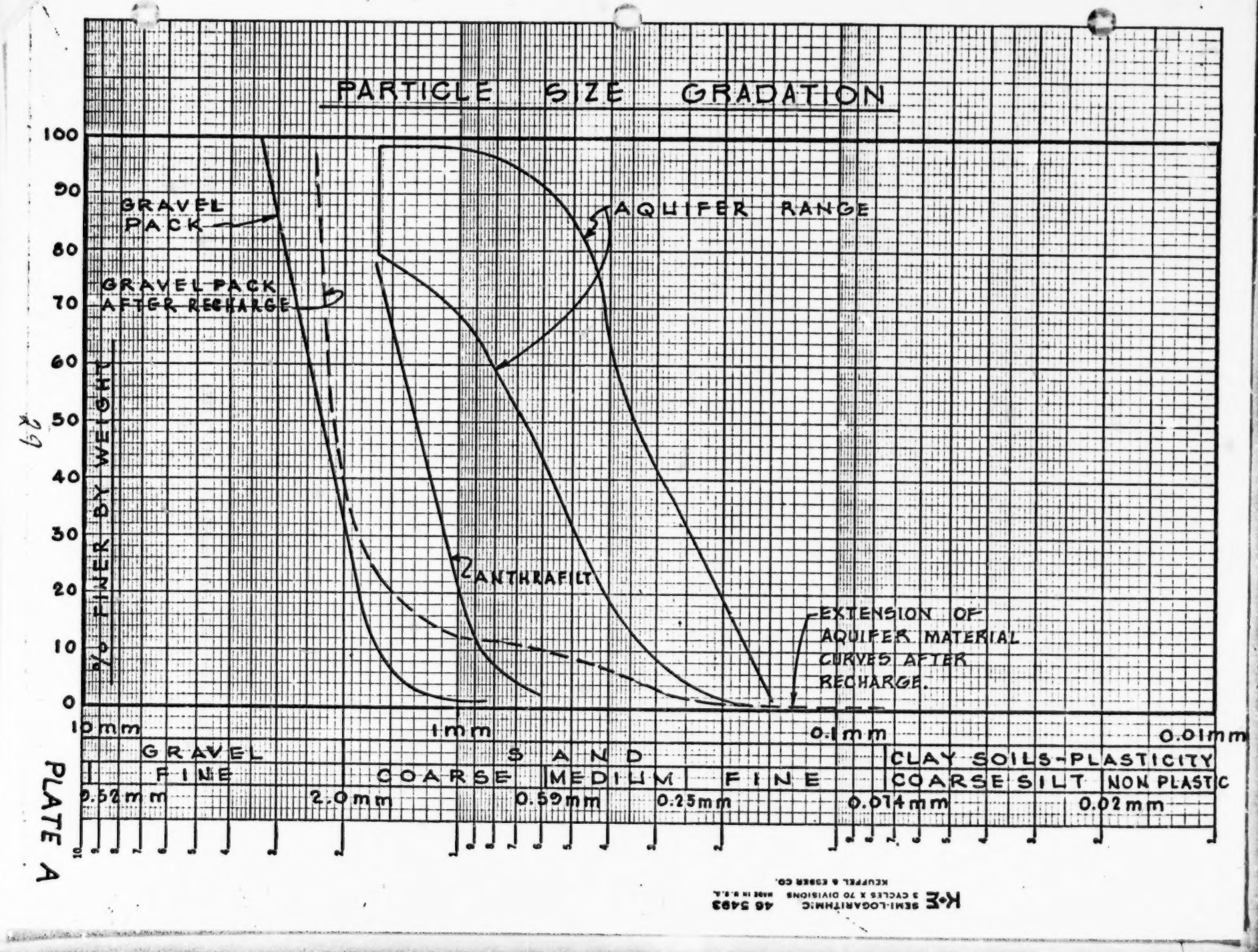
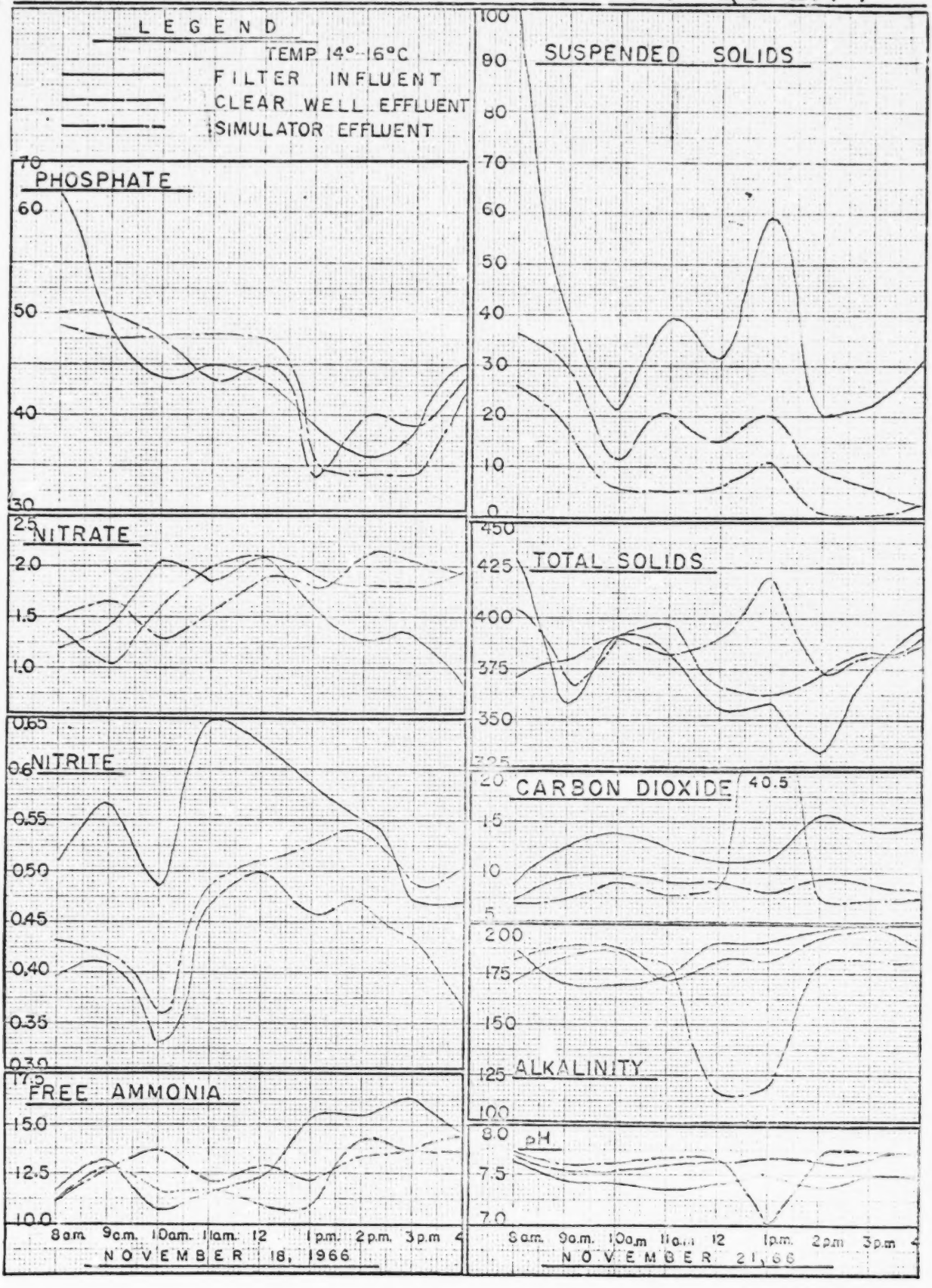


PLATE A

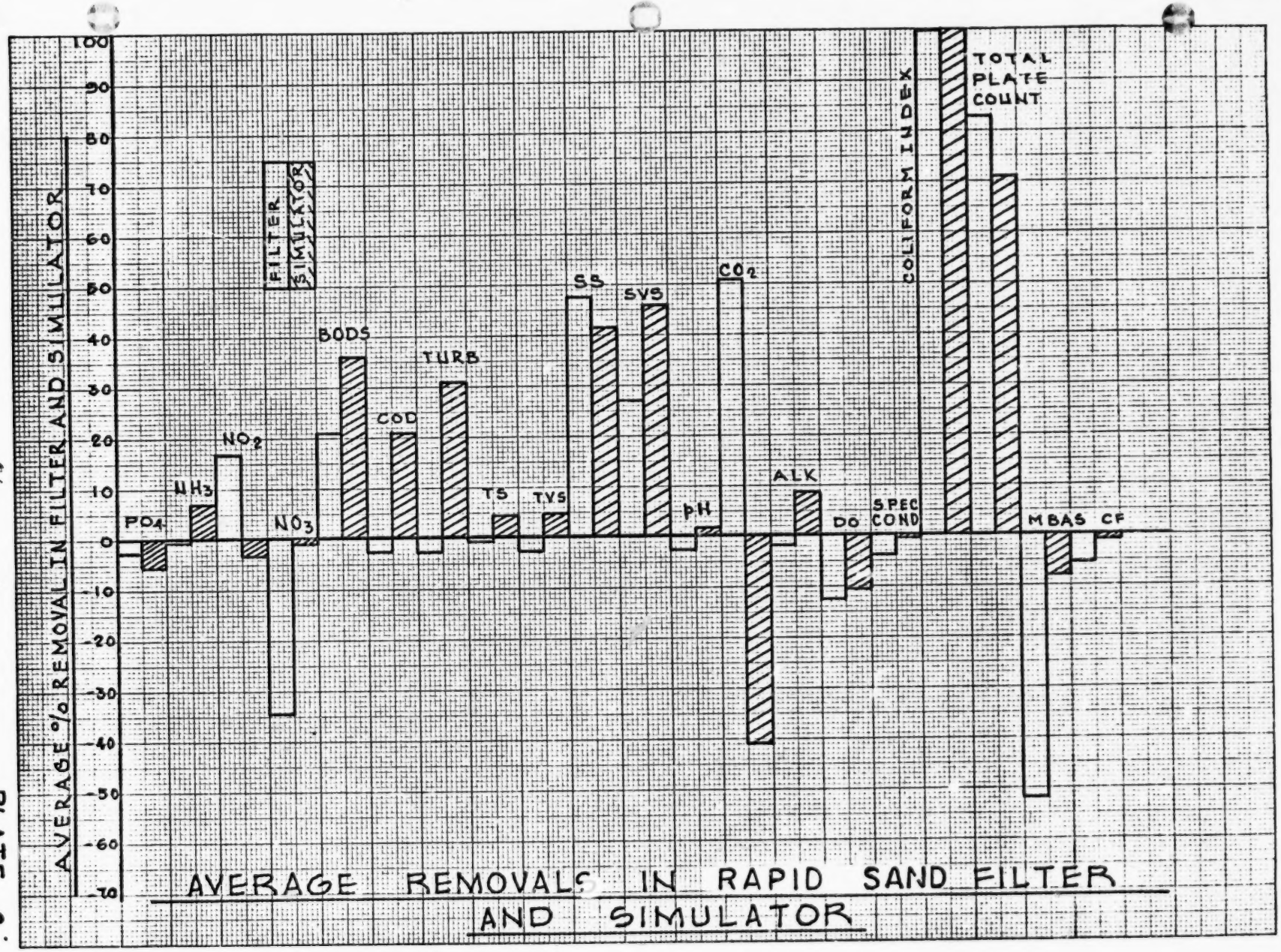
K-E SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

TRICKLING FILTER EFFLUENT QUALITY



K&E 10 X 10 TO THE CENTIMETER 46 1513
KEUFFEL & ESSER CO. MADE IN U.S.A.

PLATE B



AVERAGE REMOVALS IN RAPID SAND FILTER AND SIMULATOR

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PLATE C.

K-E 10 X 10 TO THE CENTIMETER 46 1513
10 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

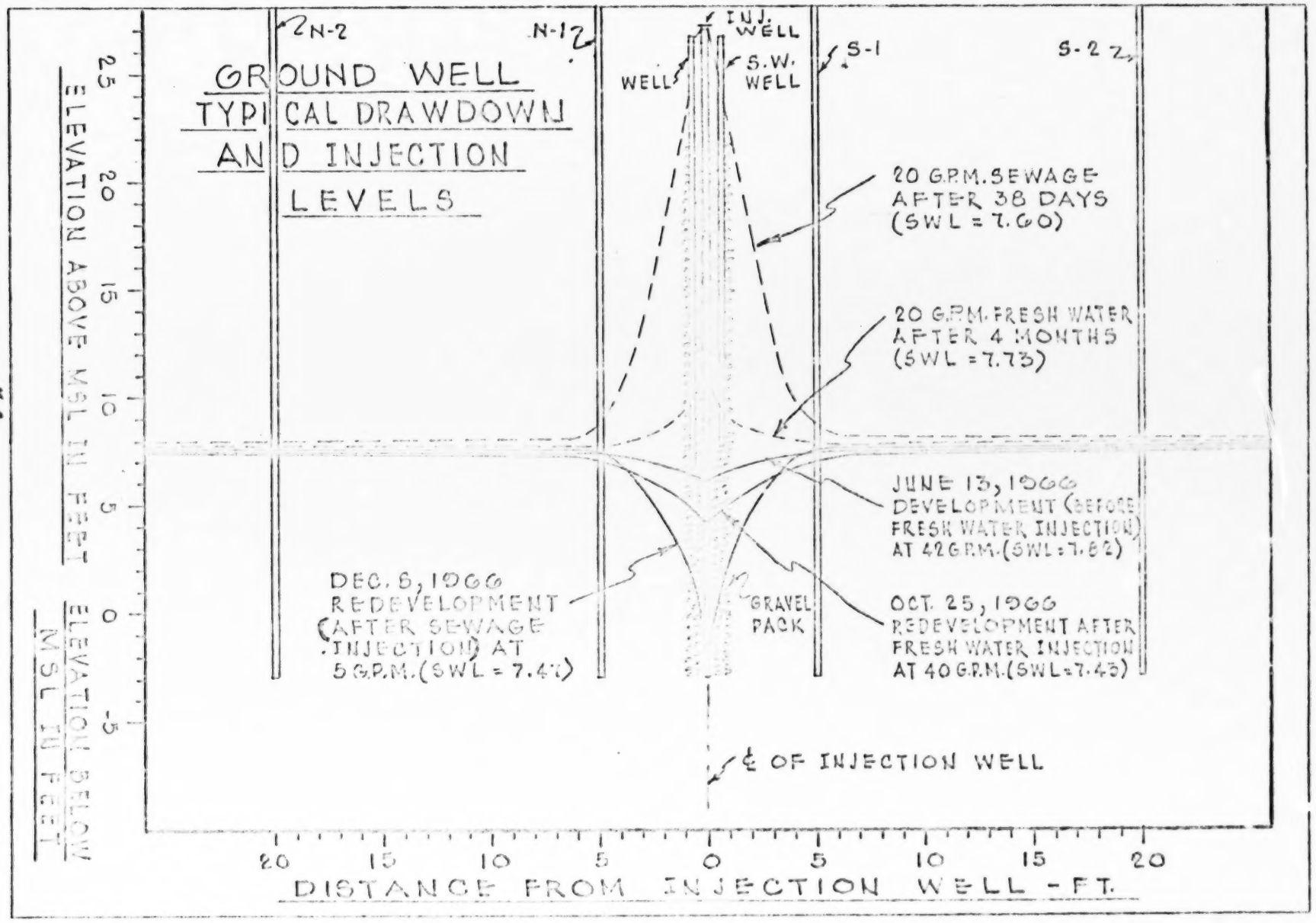
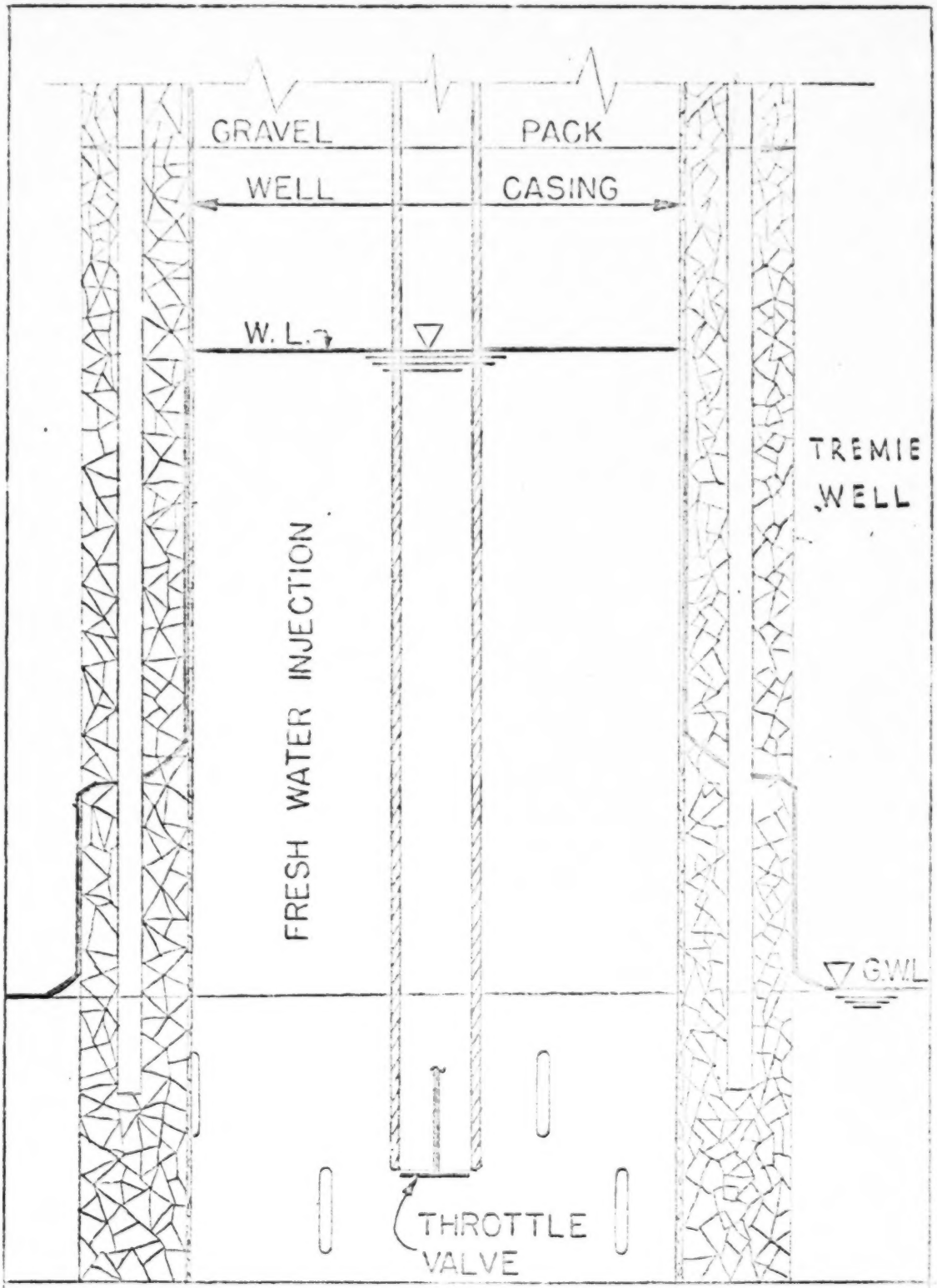
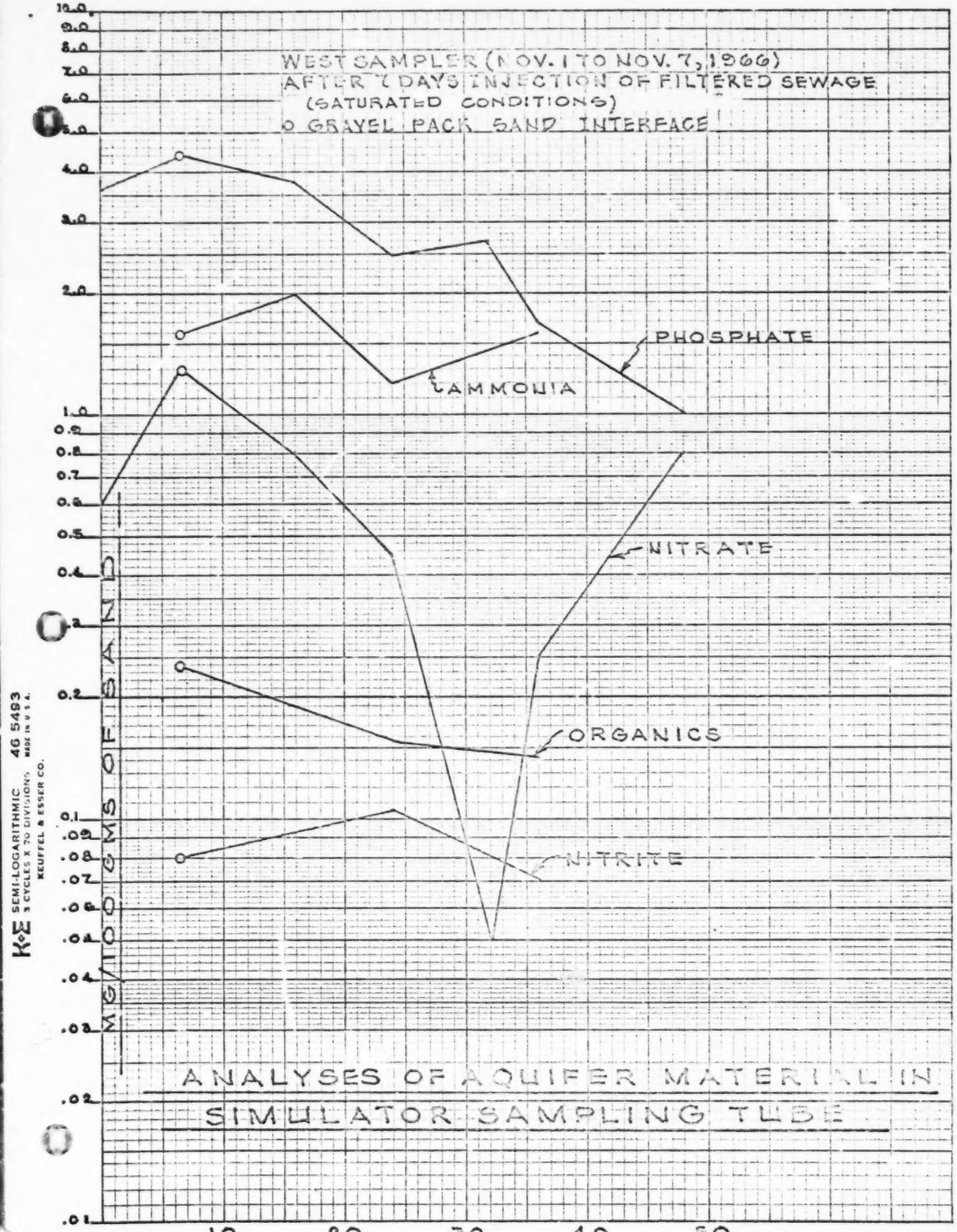

GROUND WELL
TYPICAL DRAWDOWN
AND INJECTION
LEVELS
N-2
N-1
INJ. WELL
S.W. WELL
S-1
S-2
20 G.P.M. SEWAGE AFTER 38 DAYS (SWL = 7.60)
20 G.P.M. FRESH WATER AFTER 4 MONTHS (SWL = 7.73)
JUNE 13, 1966 DEVELOPMENT (BEFORE FRESH WATER INJECTION) AT 42 G.P.M. (SWL = 7.82)
DEC. 6, 1966 REDEVELOPMENT (AFTER SEWAGE INJECTION) AT 5 G.P.M. (SWL = 7.47)
GRAVEL PACK
OCT. 25, 1966 REDEVELOPMENT AFTER FRESH WATER INJECTION AT 40 G.P.M. (SWL = 7.43)
℄ OF INJECTION WELL
ELEVATION ABOVE MSL IN FEET
25
20
15
10
5
0
-5
ELEVATION BELOW MSL IN FEET
20
15
10
5
0
5
10
15
20
DISTANCE FROM INJECTION WELL - FT.

PLATE D



TYPICAL WATER SURFACE DURING INJECTION

PLATE E



ANALYSES OF AQUIFER MATERIAL IN SIMULATOR SAMPLING TUBE

PLATE F

K&E SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

K&E 10 X 10 TO THE CENTIMETER 46 1513
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO.

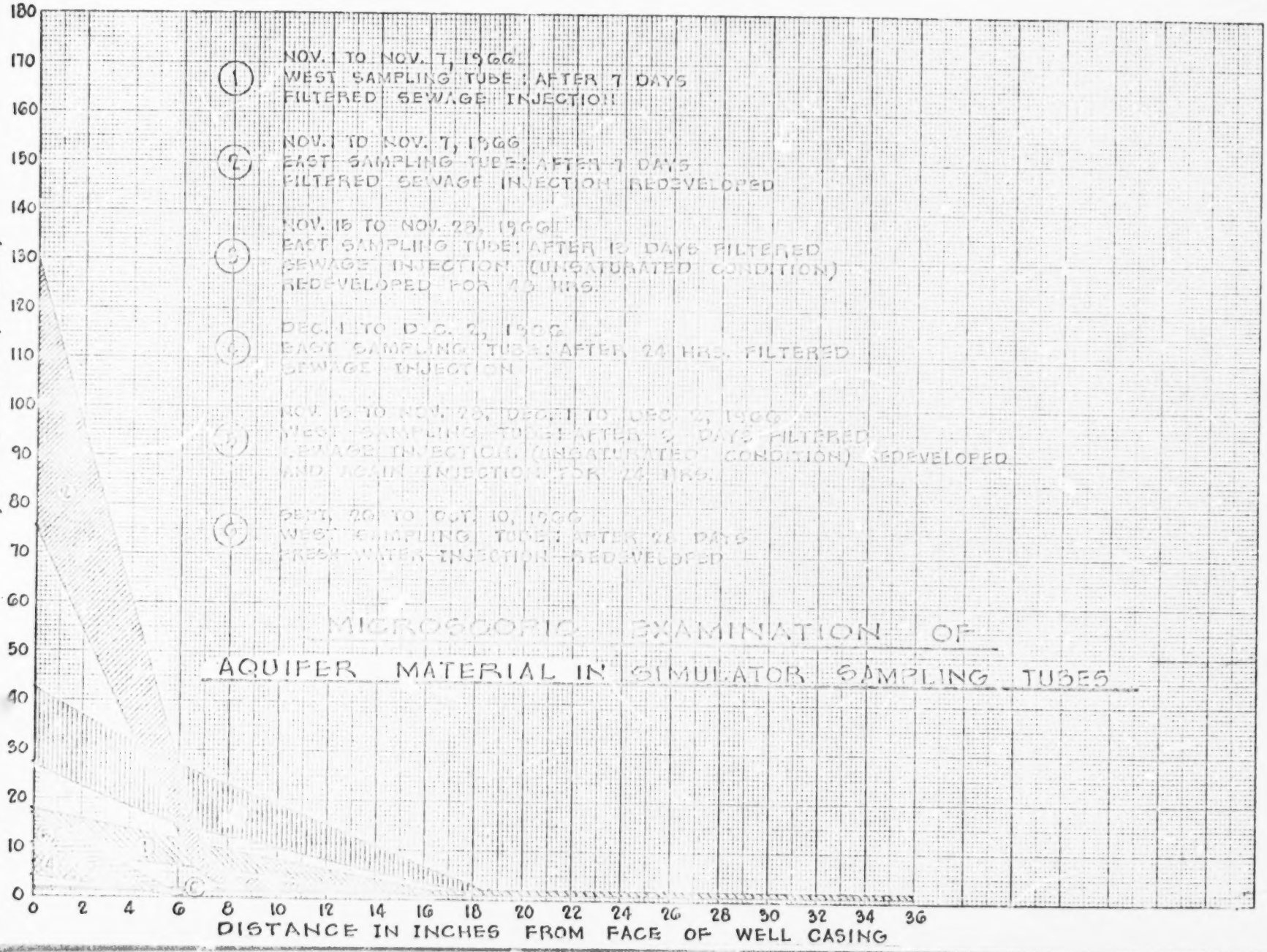

(ALGAE/SAMPLE) X 10⁴
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
DISTANCE IN INCHES FROM FACE OF WELL CASING
1 NOV. 1 TO NOV. 7, 1966
WEST SAMPLING TUBE: AFTER 7 DAYS
FILTERED SEWAGE INJECTION
2 NOV. 1 TO NOV. 7, 1966
EAST SAMPLING TUBE: AFTER 7 DAYS
FILTERED SEWAGE INJECTION REDEVELOPED
3 NOV. 15 TO NOV. 28, 1966
EAST SAMPLING TUBE: AFTER 13 DAYS FILTERED
SEWAGE INJECTION (UNSATURATED CONDITION)
REDEVELOPED FOR 48 HRS.
4 DEC. 1 TO D_C. 2, 1966
EAST SAMPLING TUBE: AFTER 24 HRS. FILTERED
SEWAGE INJECTION
5 NOV. 15 TO NOV. 28, DEC. 1 TO DEC. 2, 1966
WEST SAMPLING TUBE: AFTER 2 DAYS FILTERED
SEWAGE INJECTION (UNSATURATED CONDITION) REDEVELOPED
AND AGAIN INJECTED FOR 24 HRS.
6 SEPT. 20 TO OCT. 10, 1966
WEST SAMPLING TUBE: AFTER 21 DAYS
FRESH WATER INJECTION REDEVELOPED
MICROSCOPIC EXAMINATION OF
AQUIFER MATERIAL IN SIMULATOR SAMPLING TUBES

PLATE G 35

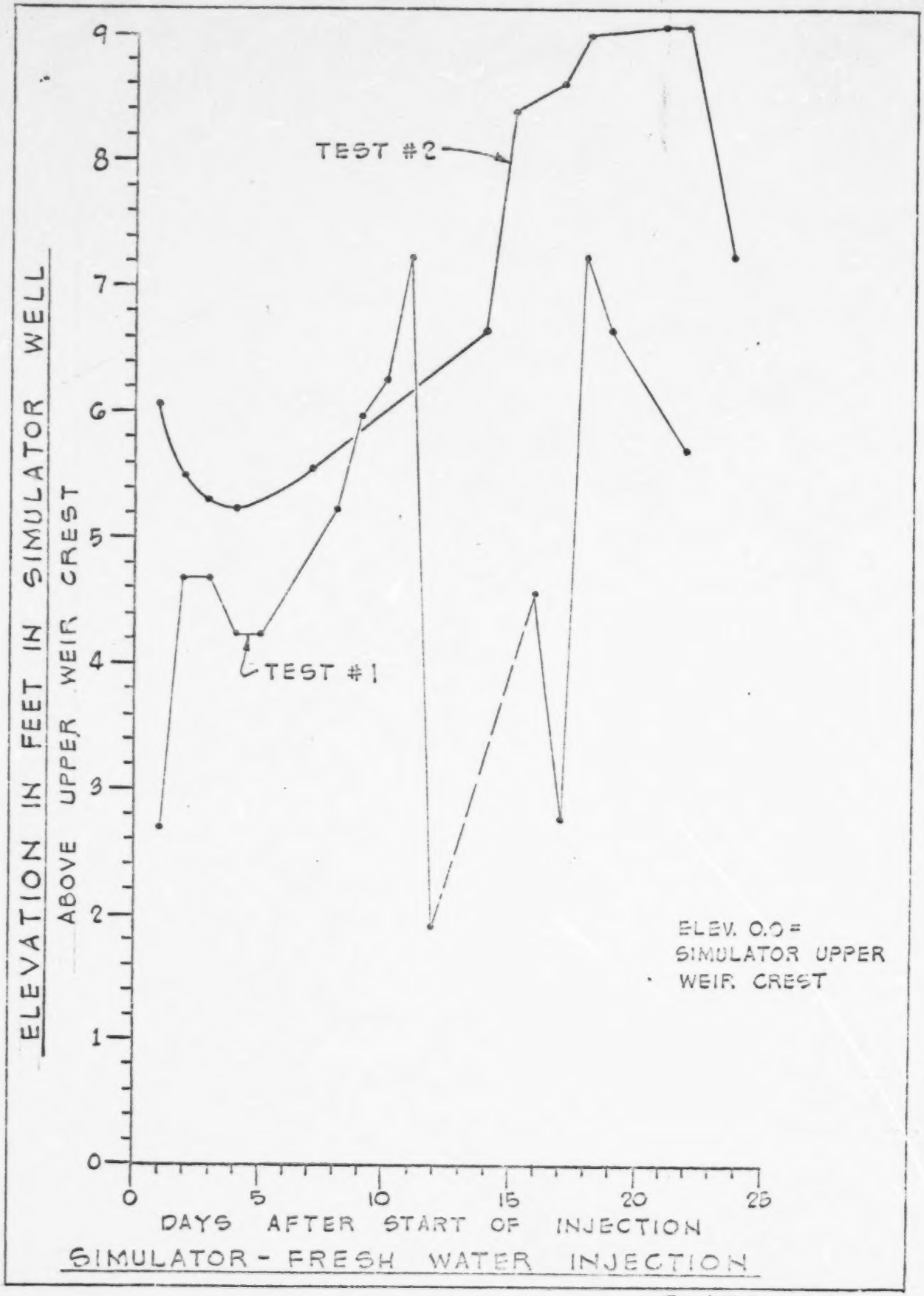

ELEVATION IN FEET IN SIMULATOR WELL
ABOVE UPPER WEIR CREST
0
1
2
3
4
5
6
7
8
9
TEST #2
TEST #1
ELEV. 0.0 =
SIMULATOR UPPER
WEIR CREST
0
5
10
15
20
25
DAYS AFTER START OF INJECTION
SIMULATOR - FRESH WATER INJECTION

PLATE H

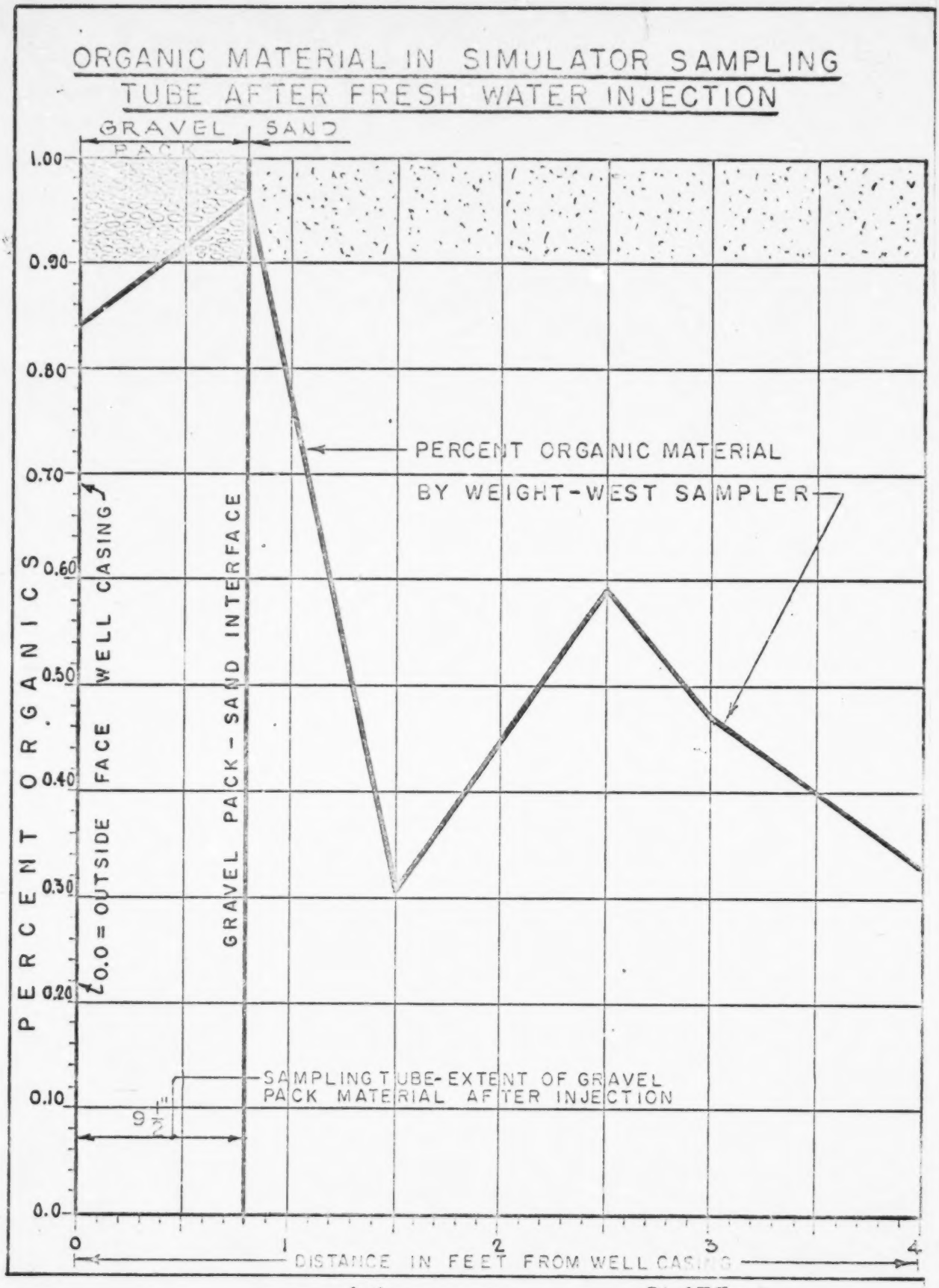
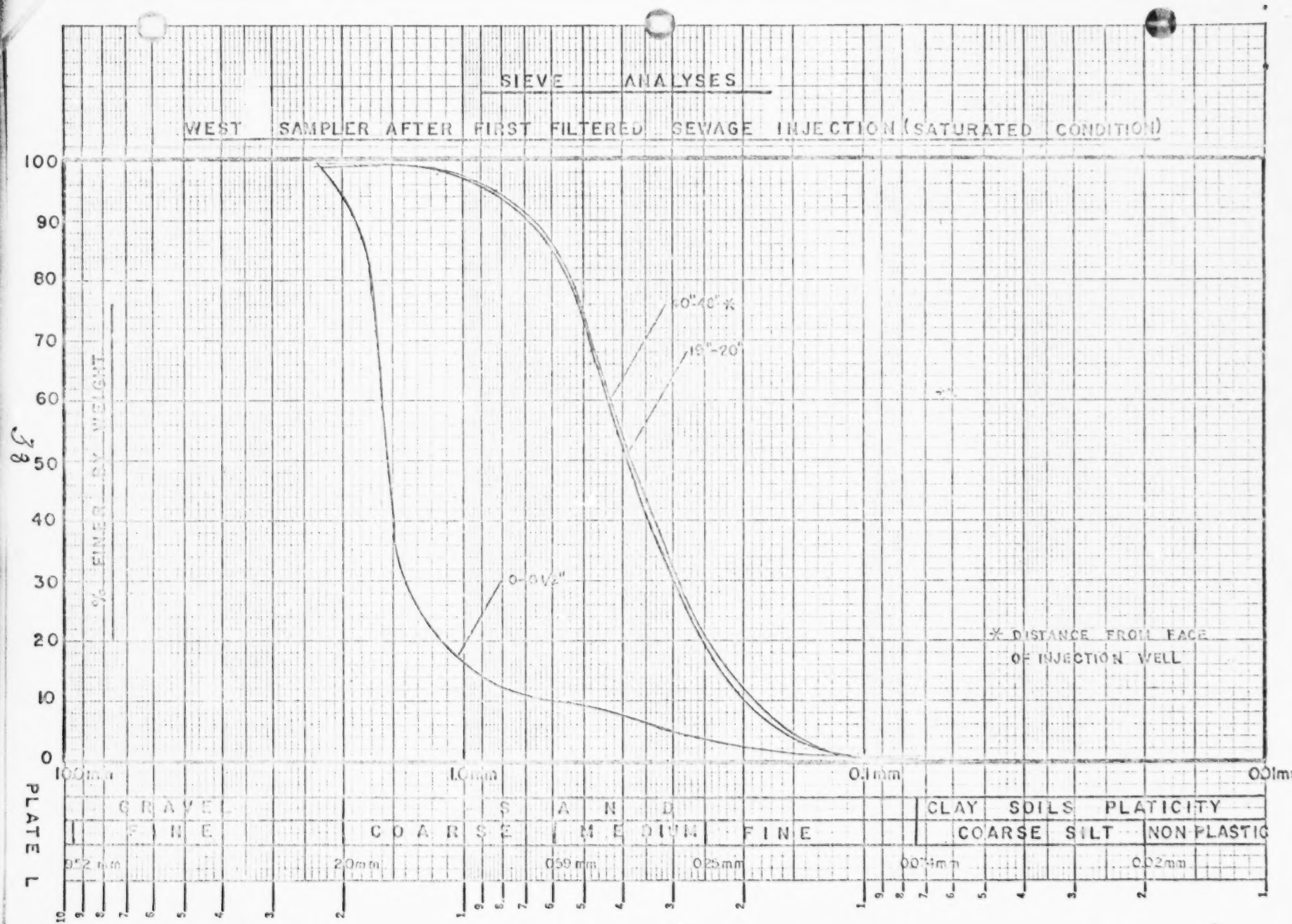

ORGANIC MATERIAL IN SIMULATOR SAMPLING TUBE AFTER FRESH WATER INJECTION
GRAVEL PACK
SAND
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.0
PERCENT ORGANICS
0.0 = OUTSIDE FACE WELL CASING
GRAVEL PACK - SAND INTERFACE
PERCENT ORGANIC MATERIAL BY WEIGHT-WEST SAMPLER
SAMPLING TUBE-EXTENT OF GRAVEL PACK MATERIAL AFTER INJECTION
9 1/2"
0
1
2
3
4
DISTANCE IN FEET FROM WELL CASING

PLATE 1


SIEVE ANALYSES
WEST SAMPLER AFTER FIRST FILTERED SEWAGE INJECTION (SATURATED CONDITION)
% FINER BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
0"-40" *
15"-20"
0-0½"
* DISTANCE FROM FACE OF INJECTION WELL
100mm
10mm
0.1mm
0.01mm
GRAVEL
SAND
CLAY SOILS PLATICITY
FINE
COARSE
MEDIUM
FINE
COARSE SILT
NON PLASTIC
2.0mm
0.59mm
0.25mm
0.074mm
0.02mm
PLATE L

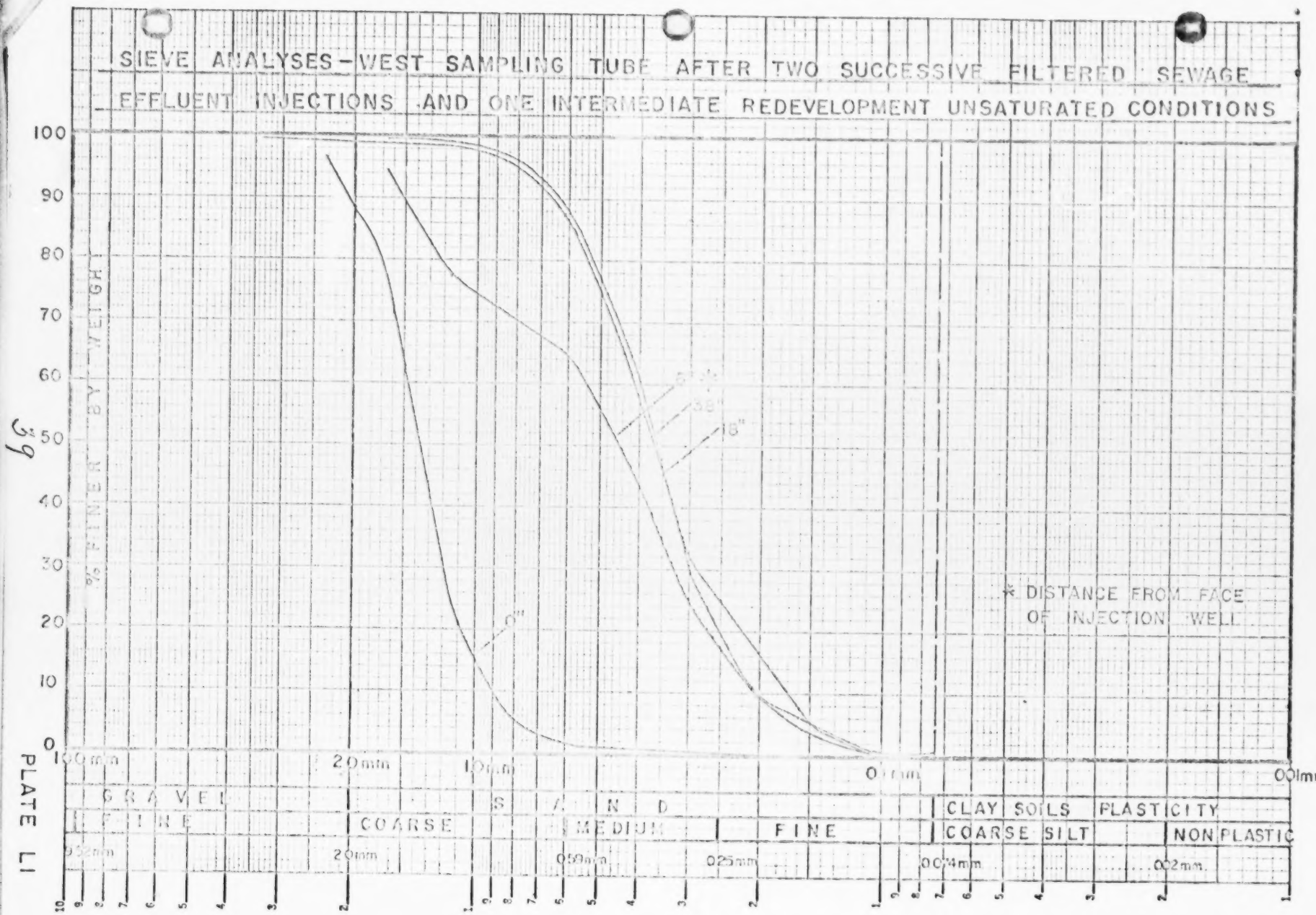


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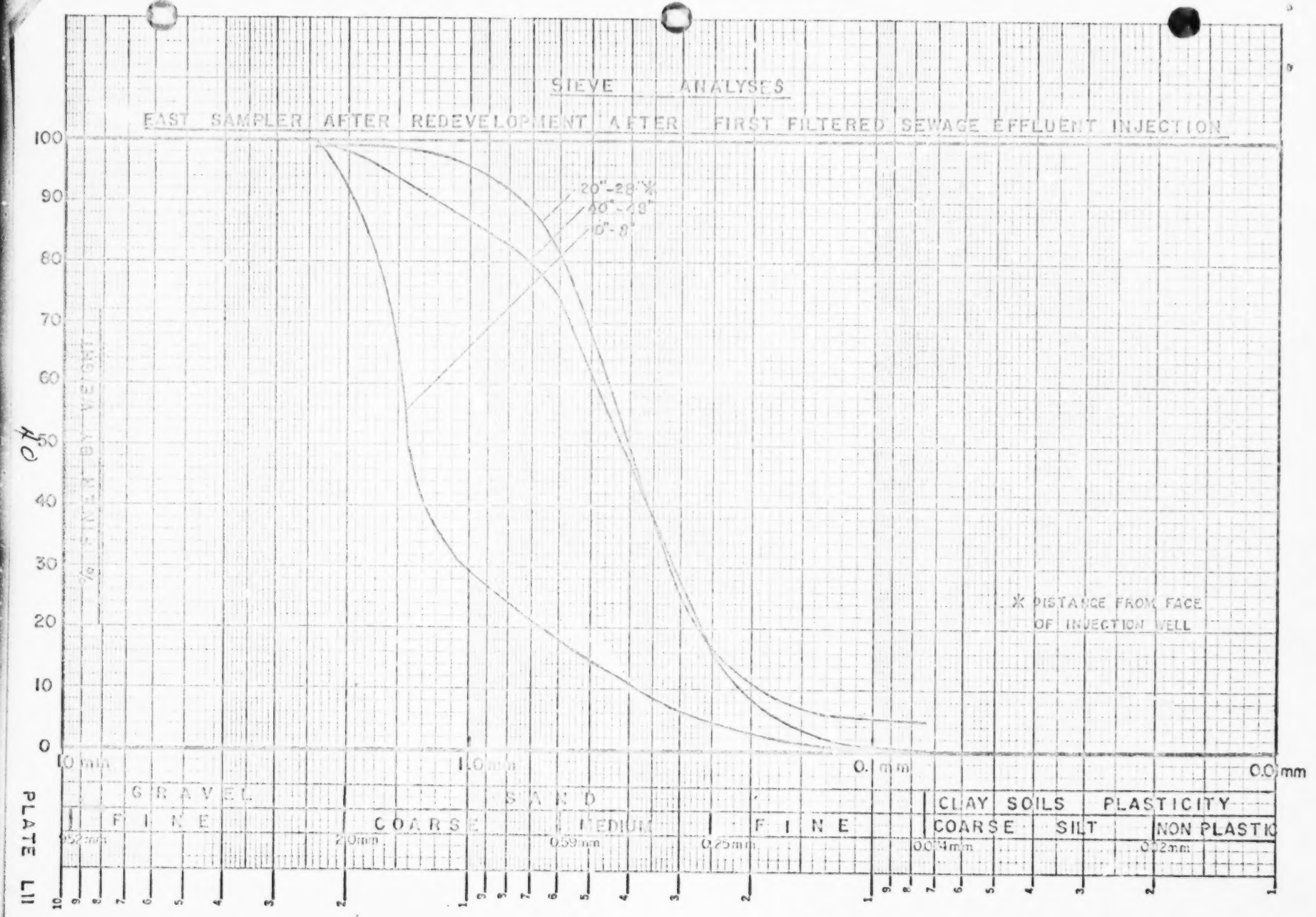
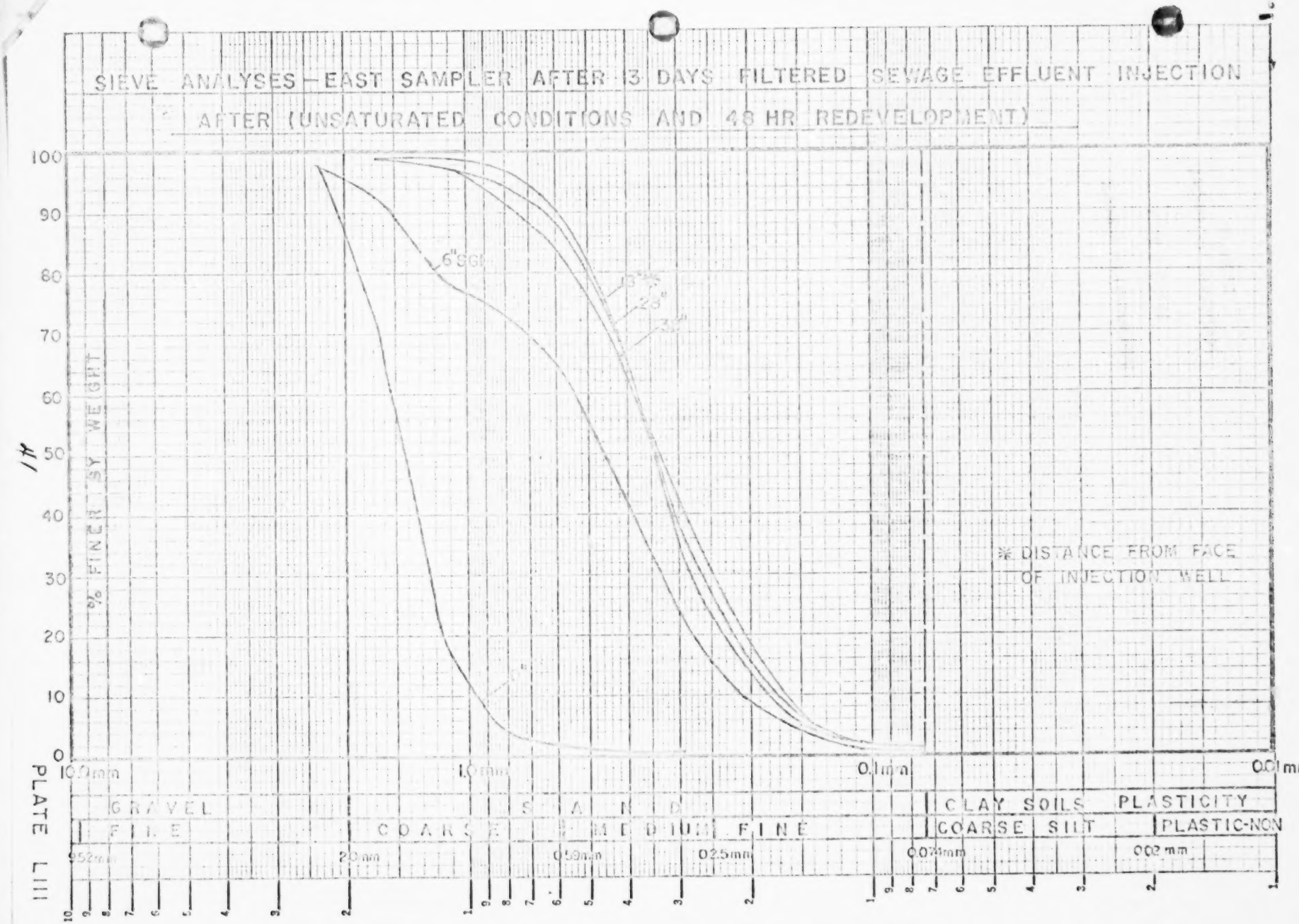
PLATE LI

KEUFFEL & ESSER CO.
K&E SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS MFG. IN U.S.A.


SIEVE ANALYSES
EAST SAMPLER AFTER REDEVELOPMENT AFTER FIRST FILTERED SEWAGE EFFLUENT INJECTION
20"-28"*
40"-48"
6"-8"
% FINER BY WEIGHT
* DISTANCE FROM FACE OF INJECTION WELL
10 mm
1.0 mm
0.1 mm
0.01 mm
GRAVEL
SAND
CLAY SOILS
PLASTICITY
FINE
COARSE
MEDIUM
FINE
COARSE
SILT
NON PLASTIC
2.0mm
0.59mm
0.25mm
0.074mm
0.02mm
PLATE LII


SIEVE ANALYSES—EAST SAMPLER AFTER 13 DAYS FILTERED SEWAGE EFFLUENT INJECTION
AFTER (UNSATURATED CONDITIONS AND 48 HR REDEVELOPMENT)
% FINER BY WEIGHT
6"
13"
23"
* DISTANCE FROM FACE OF INJECTION WELL
GRAVEL
SAND
CLAY SOILS PLASTICITY
FINE
COARSE
MEDIUM
FINE
COARSE SILT
PLASTIC-NON
PLATE III